U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

PB-256 944

The Cost of Columnar Denitrification for Removal of Nitrogen from Wastewater

National Environmental Research Center

January 1972

BIBLIOGRAPHIC DATA SHEET	1. Report No.	2.	3. Recipient's Accession No. PB-256 944
4. Title and Subtitle The Cost of Columnar Denitrification for Removal of Nitrogen From Wastewater.			5. Report Date January 1972 6.
7. Author(s) Robert Smith			8. Performing Organization Rept. No.
9. Performing Organization Name and Address National Environmental Research Center Cincinnati, Ohio Advanced Waste Treatment Research Laboratory			10. Project/Task/Work Unit No. 11. Contract/Grant No.
12. Sponsoring Organization Name and Address			13. Type of Report & Period Covered 14.

15. Supplementary Notes

16. Abstracts

The report presents the results of a study to examine the practicability and cost of columnar denitrification of secondary effluent. The purpose of the denitrification process is to reduce the nitrate ion, thus releasing nitrogen as nitrogen gas. The basic design assumptions are presented. Columnar denitrification is an alternative to denitrification in dispersed floc reactors.

17. Key Words and Document Analysis. 17a. Descriptors

*Waste water
*Nitrification
*Sewage treatment
*Industrial waste treatment
Gases
Nitrogen
Design
Carbinols
Pressure vessels
Cost estimates
Pumping

17b. Identifiers/Open-Ended Terms

*Denitrification

17c. COSATI Field/Group 13B

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
National Technical Information Service Springfield, VA 22161	UNCLASSIFIED	44
	20. Security Class (This Page) UNCLASSIFIED	22. Price PC$4.00/ MF$2.25

FORM NTIS-35 (REV. 10-73) ENDORSED BY ANSI AND UNESCO. THIS FORM MAY BE REPRODUCED USCOMM-DC 8265-P74

NOTICE

This document is a preliminary draft. It has not been formally released by EPA and should not at this stage be construed to represent Agency policy. It is being circulated for comment on its technical accuracy and policy implications.

246065

PB 256 944

002218

THE COST OF COLUMNAR DENITRIFICATION FOR REMOVAL OF NITROGEN FROM WASTEWATER

by

Robert Smith

ENVIRONMENTAL PROTECTION AGENCY
Office of Research and Monitoring
Advanced Waste Treatment Research Laboratory
Cincinnati, Ohio

January, 1972

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE

THE COST OF COLUMNAR DENITRIFICATION FOR REMOVAL OF NITROGEN FROM WASTEWATER

This report presents the results of a study to examine the practicability and cost of columnar denitrification of secondary effluent. The purpose of the denitrification process is to reduce the nitrate ion, thus releasing nitrogen as nitrogen gas. The basic design assumptions are presented in Table I. Columnar denitrification is an alternative to denitrification in dispersed floc reactors. The addition of methanol is required for both processes. The cost of denitrification in dispersed floc reactors was presented in memorandum to F. M. Middleton, dated November 25, 1970. All costs in this report are keyed to January, 1971.

DENITRIFICATION CONTACTORS

An application rate of 7 gpm/sq ft was selected as the maximum rate allowable to achieve denitrification. The required height of the ¼ inch diameter media can then be computed from the following relationship based on open bed contact time:

Length of Media, ft = (gpm/sq ft) x (contact time, min)/7.48

Thus, the required length of media is 14 ft. In the design of carbon contactors, it has generally been accepted that the length of the column should equal or exceed the diameter. This design criterion is believed to be necessary to assure good distribution and to minimize channeling. For open contactors in which atmospheric pressure is used to force the water through the media, this criterion is generally not followed. Clearly the length to diameter ratio required is related to

Table I

DESIGN CRITERIA FOR COLUMNAR DENITRIFICATION

PROCESS ELEMENT	DESIGN CRITERION USED
1. Pressure Vessels	Diameter set at 12 feet, the maximum size which can be shop fabricated and then transported to the plant site Wall thickness set by ASME Code for 50 psig internal pressure Wall thickness = 7/16 inch Application rate set at 7 gpm/sq. ft., based on peak flow Contact time set at 15 minutes, based on empty bed ¼ inch diameter rock media (59 cy/column) Leopold bottoms Depth of rock media = 14 ft. High build epoxy lining provided 150% for bed expansion during backwash Height of cylindrical section = 21 ft.
2. Pressure Vessel Piping and Controls	5-7 ft/sec flow velocity Orifices and control valves to equalize flow between columns All contactors in parallel Piping arranged so any column can be bypassed for maintenance and cleaning All piping schedule 40 Carbon steel process and steam flanged pipe
3. Pumping Facilities	Peak/average ratio = 2.0 for 1 mgd 1.6 for 10 mgd 1.3 for 100 mgd Raw wastewater pump station estimated as lump sum

Table I (continued)

DESIGN CRITERIA FOR COLUMNAR DENITRIFICATION

PROCESS ELEMENT	DESIGN CRITERION USED
3. Pumping Facilities (continued)	FloMatcher equipment provided to vary flow rate through columns Backwash at 20 gpm/sq. ft., 75 ft. head Surface wash at 160 gpm at 300 ft. head Backwash time 15 min./day/column
4. Methanol Feeding and Storage	Average dose 60 mg/l Storage capacity 8,000 gal. at 1 mgd 20,000 gal. at 10 mgd 100,000 gal. at 100 mgd Steel underground tanks lined with baked phenolic Methanol feed pumps 500 lb/day/mg 76 gal/day/mg 3.1 gal/hr/mg Use 6 gph for 1 mgd 60 gph for 10 mgd 600 gph for 100 mgd Head tank at 5 minutes detention time Control equipment to pace methanol feed with flow

the application rate. Since a 12 ft. diameter pressure vessel is the largest vessel which can be easily transported from the shop to the plant site, and because 12 ft. is just under the required 14 feet column height, this design was based on the use of 12 foot diameter pressure vessels. The economic advantages associated with the use of field errected pressure vessels greater in diameter than 12 ft. will be studied at some later time.

Since 150% of the column must be provided to allow for backwash, the length of the cylindrical section of the contactor was set at 21 ft.

To determine the required wall thickness, the following relationship from the ASME code for pressure vessels was used:

$$t = \frac{PR}{SE - 0.6P}$$

t = shell thickness, inches
P = design pressure, psi
S = working stress, psi
E = joint efficiency
R = inside radius, inches

The allowable tensile stress for SA-30 steel is 13,750 psi. Using a design pressure of 50 psi and a joint efficiency of 80%, the thickness for a 12 ft. diameter pressure vessel was computed from the above formula as 0.328 inches. The next largest standard plate thickness, 7/16 inch, was used in estimating the cost of the pressure vessel.

A sketch of the contactor for columnar denitrification is shown in Figure 1. A cost estimate for shop fabrication and lining of this

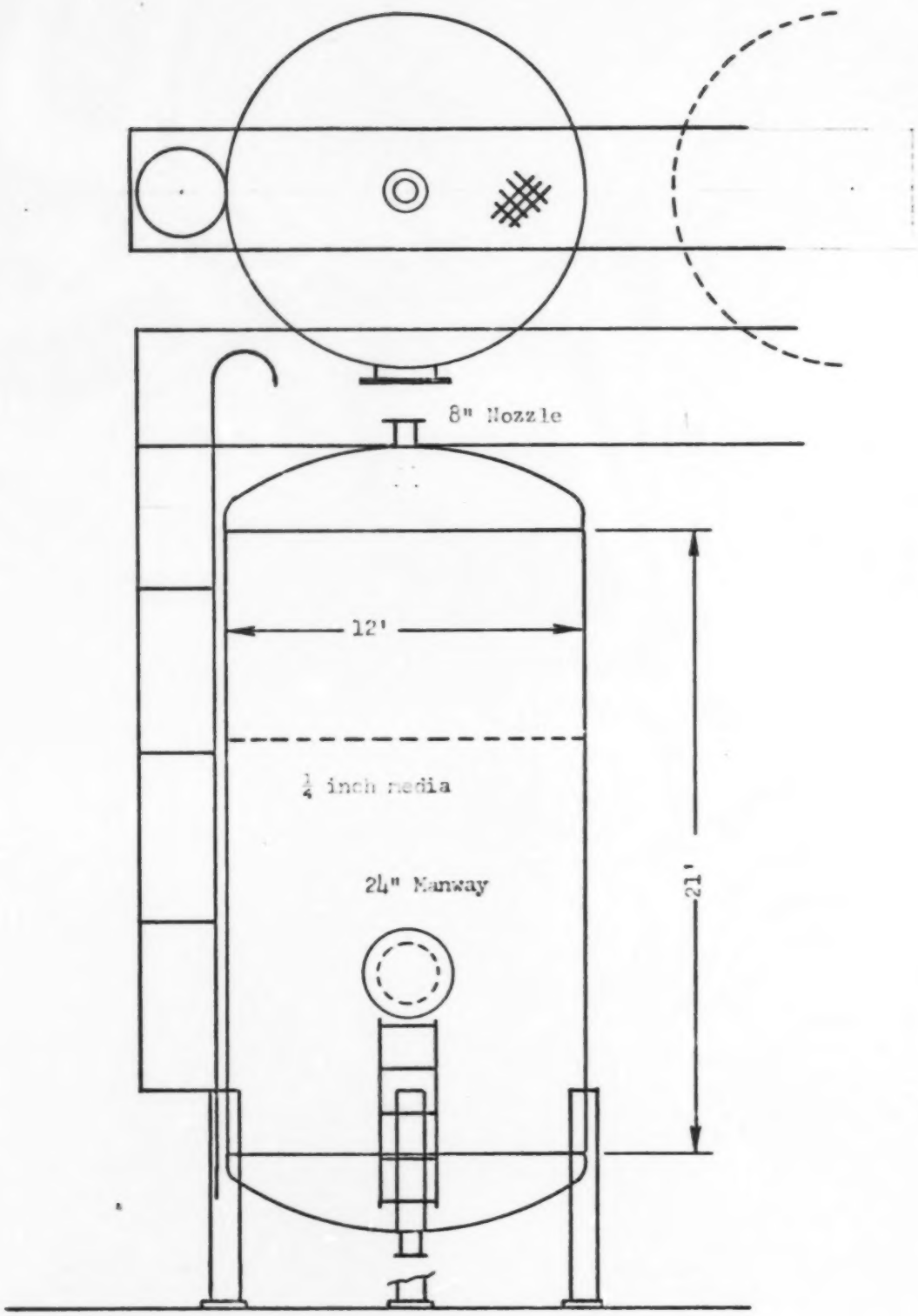


FIGURE 1

vessel is given in Table II. These cost estimates were taken from manuals published by International Estimating Services[1].

The number of individual contactors needed was determined from the expected peak flow. Assumed peak/average ratios are shown in Table I. The flow through each contactor should not exceed 1.14 mgd. Thus, two contactors should be adequate for the 1 mgd design capacity size plant. One spare should be added for maintenance and cleaning. Fourteen contactors should be adequate for the 10 mgd size. If we add one contactor for ease of cleaning and maintenance, fifteen contactors will be required for the 10 mgd design capacity size. Similiarly, the number of contactors at the 100 mgd size would be 115. Basing the number of contactors on the peak flow might be unnecessarily conservative. The number of contactors needed will depend on the specific requirement for nitrogen removal as well as a more complete understanding of the time dependent performance characteristics of the columnar denitrification process.

PIPING AND CONTROLS FOR DENITRIFICATION

In sizing the piping for any wastewater treatment process, the choice is between making the diameter of the pipes larger and minimizing the power consumed by hydraulic friction, or making the pipe diameter smaller and accepting the additional power consumption. The optimum solution to this problem depends on the particular piping configuration and although many studies have been made, no general solution is available. Perry's Chemical Engineer's Handbook[2] relates the most cost effective flow velocity to fluid density as shown in Figure 2. For

TABLE II

COST ESTIMATE FOR DENITRIFICATION PRESSURE VESSEL

	Weight (lbs.)	Cost (dollars)
144" x 7/16" Thick Rolled and Welded Pressure Vessel Shell of A-285 Pressure Vessel Quality Plant 21 ft. long	14,174	$ 2,319.66
Two 144" I.D. x 11/16" min 2:1 S.E. Heads	11,056	4,030.40
Four Angle Legs, 6" x 6½", 4 ft. long	320	121.48
Two @" Long Weld Neck Nozzle on Top & Bottom	115	348.40
One 24" Manway	1,054	1,085.26
14' x 4' Platform	1,400	667.57
Ladder, 29 ft. x 18 lb./ft. = 522 lb. x .73	522	381.06
Pipe Handrails, 36' @ $4.90	234	176.40
Ladder, Platform and Pipe Support Clips @ $8.27 ft.		173.67
Shop Handling, Shop Rework, Hydrotesting, Cleaning and Loadout (vessel weight = 15.571 tons)		686.40
Leopold Bottom		1,711.00
Surface Wash Assembly		750.00
Commercial Blast Cleaning @ 15¢ sq. ft. (1018 sq. ft.)		305.40
Prime Coat (red lead) outside @ 4.5¢ sq. ft.		45.81
High Build Epoxy Inside @ 50¢ sq. ft.		509.00
Engineering, Purchasing, Administration @ 12%		3,194.74
TOTAL	28,875	$16,506.15

K&E LOGARITHMIC 46 7520
3 X 5 CYCLES MADE IN U.S.A.
KEUFFEL & ESSER CO.

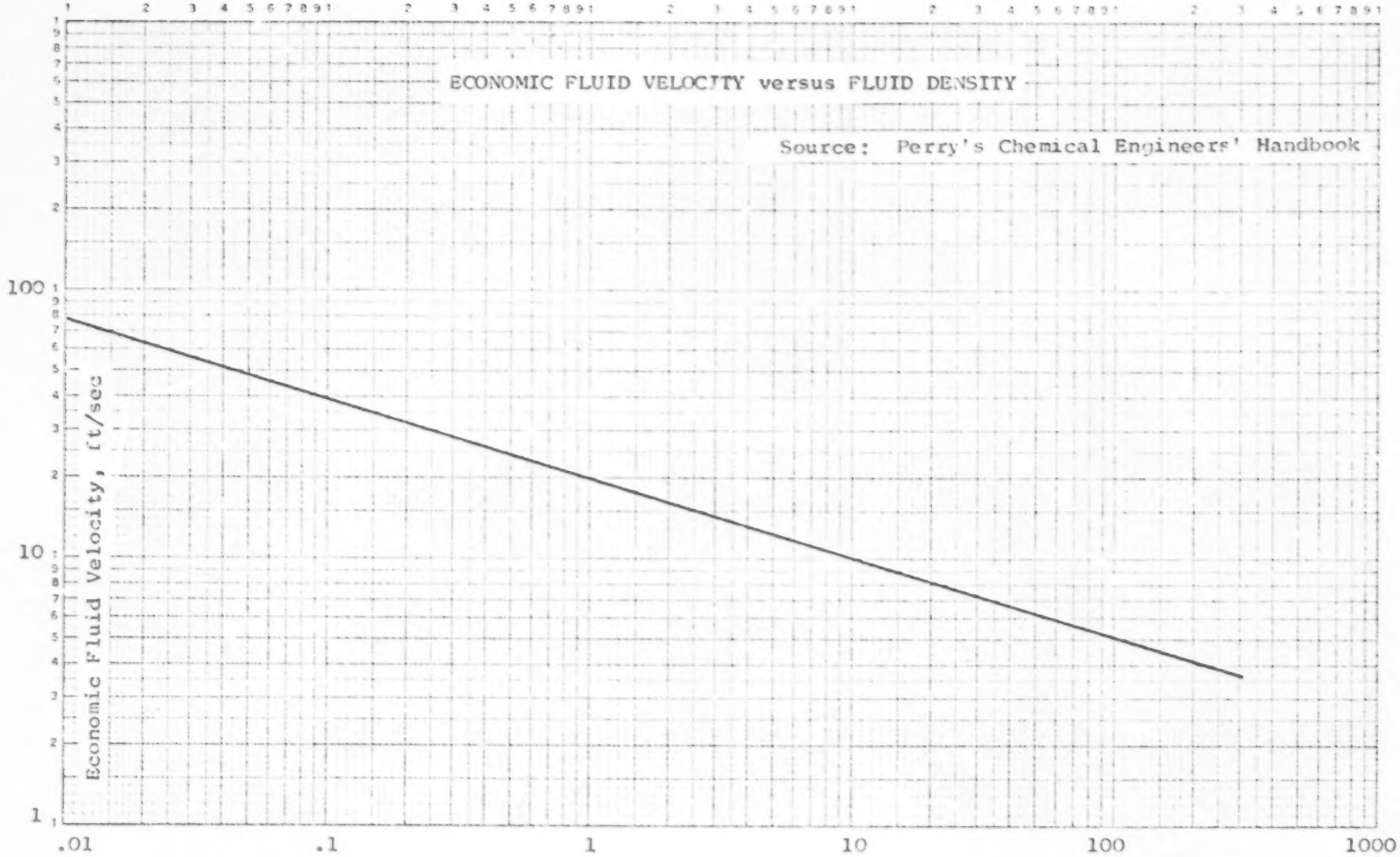


FIGURE 2

water, the recommended flow velocity is 5-6 ft/sec. It should be noted that for intermittent pumping, such as backwash and surface wash, the most cost-effective fluid velocity will be greater. A chart for determining the pipe diameter from the selected flow velocity and the design flow is shown in Figure 3. For this study, a flow velocity of 5 ft/sec was used for continuous flow and a somewhat higher velocity for intermittent flow.

Detailed piping layouts were made for a bank of five contactors with each contactor in parallel. An isometric sketch of the main piping, the backwash piping and the surface wash piping is shown in Figure 4. The three-way valves at the top of each contactor are remotely pneumatically operated and will allow the contactor to be bypassed, to be backwashed, or to be on stream. On the effluent side of each contactor a butterfly control valve is provided to control the flow through the column. This valve is pneumatically operated and is controlled by the flow orifice pressure drop to keep the flow through all columns equal. A pneumatically operated isolation valve is also provided on the effluent side of each column. On-off valves for backwash and surface wash are pneumatically operated. Sketches of bottom and top piping are shown in Figures 5 and 6. A detailed cost estimate for piping and control equipment is shown in Table III.

PUMPING FACILITIES

A pumping station similar to the recirculation or intermediate pump station for a wastewater treatment plant will be necessary to pump the secondary effluent through the denitrification contactors.

ECONOMIC DIAMETER FOR PROCESS PIPING

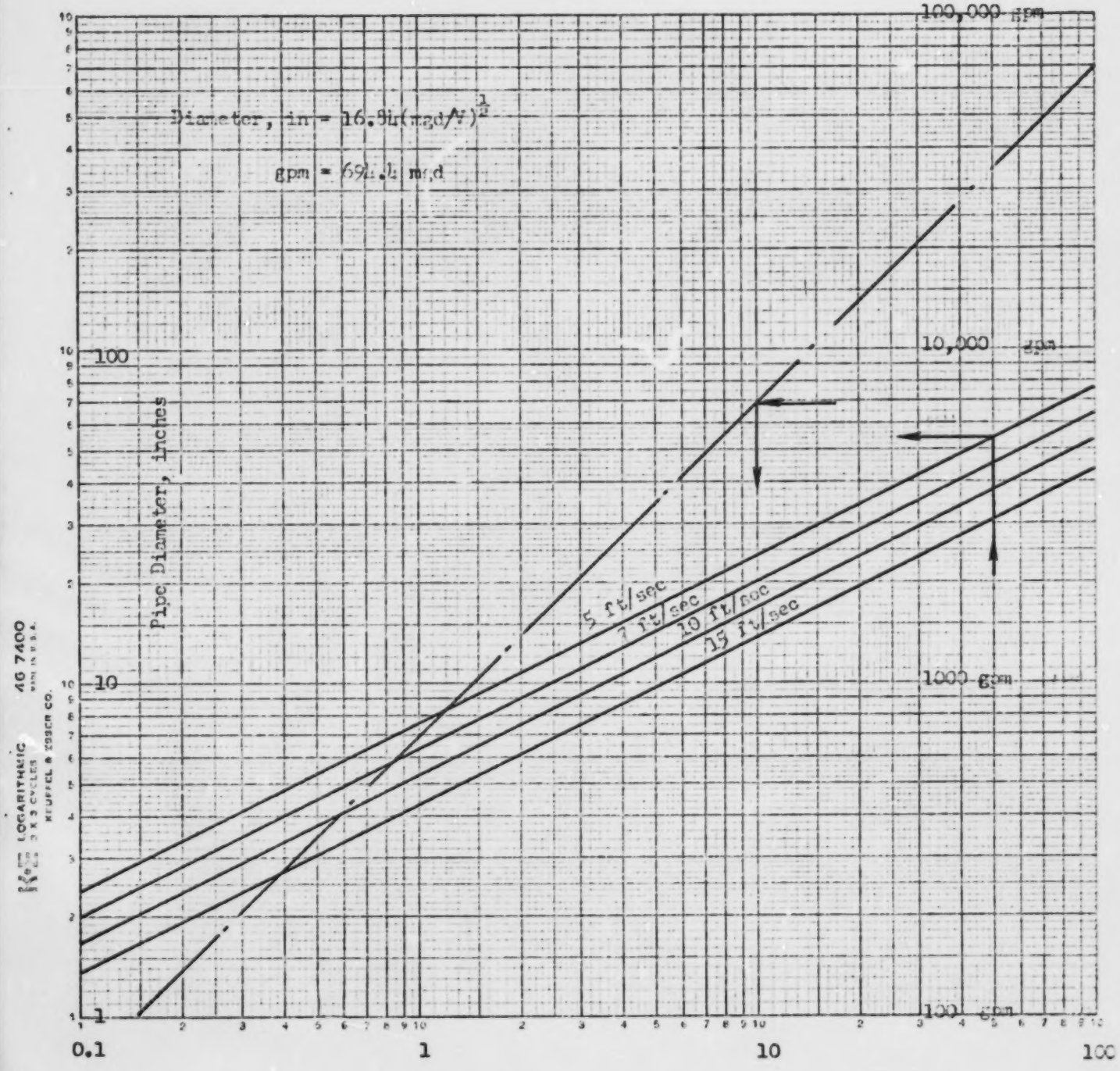
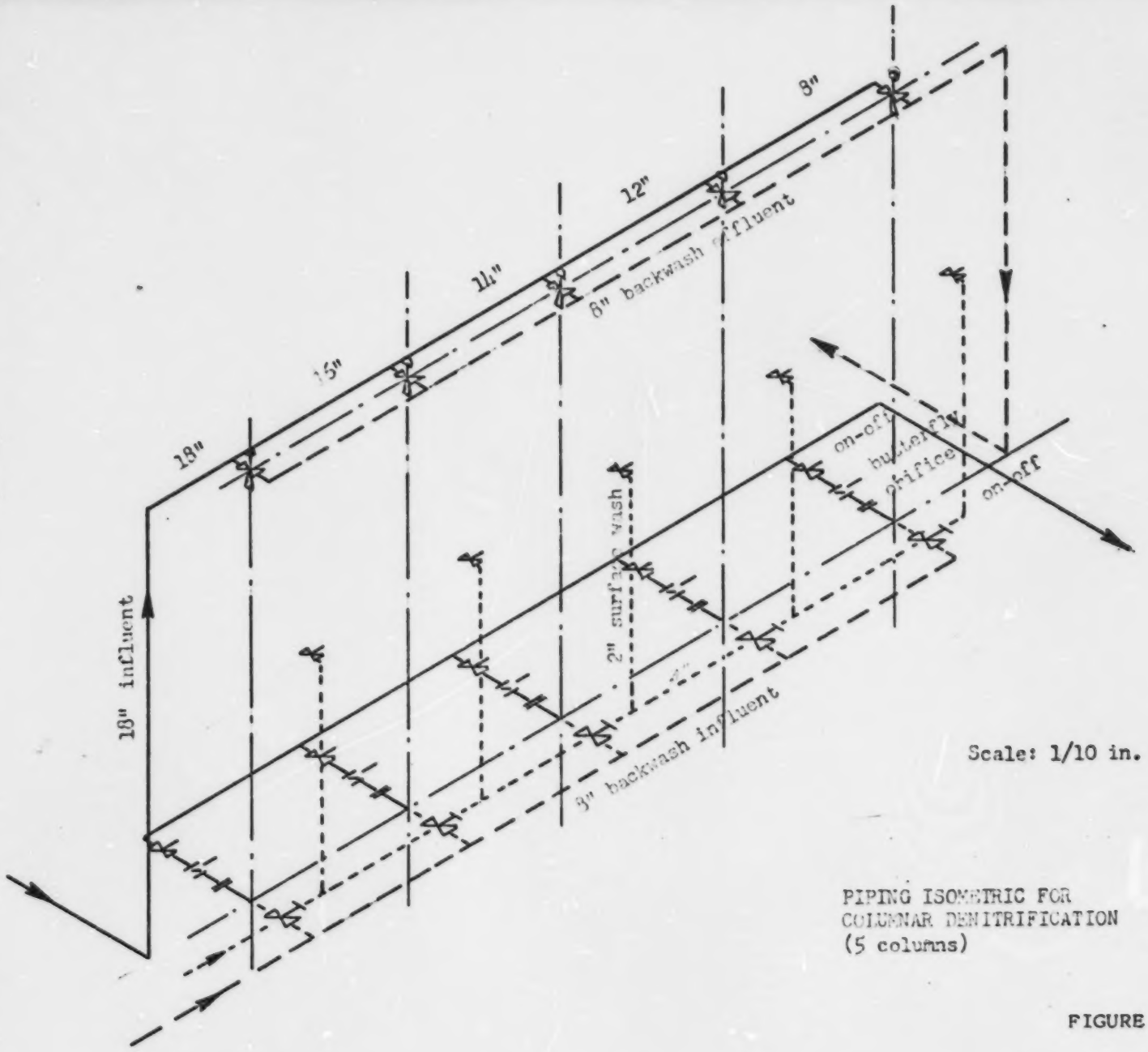


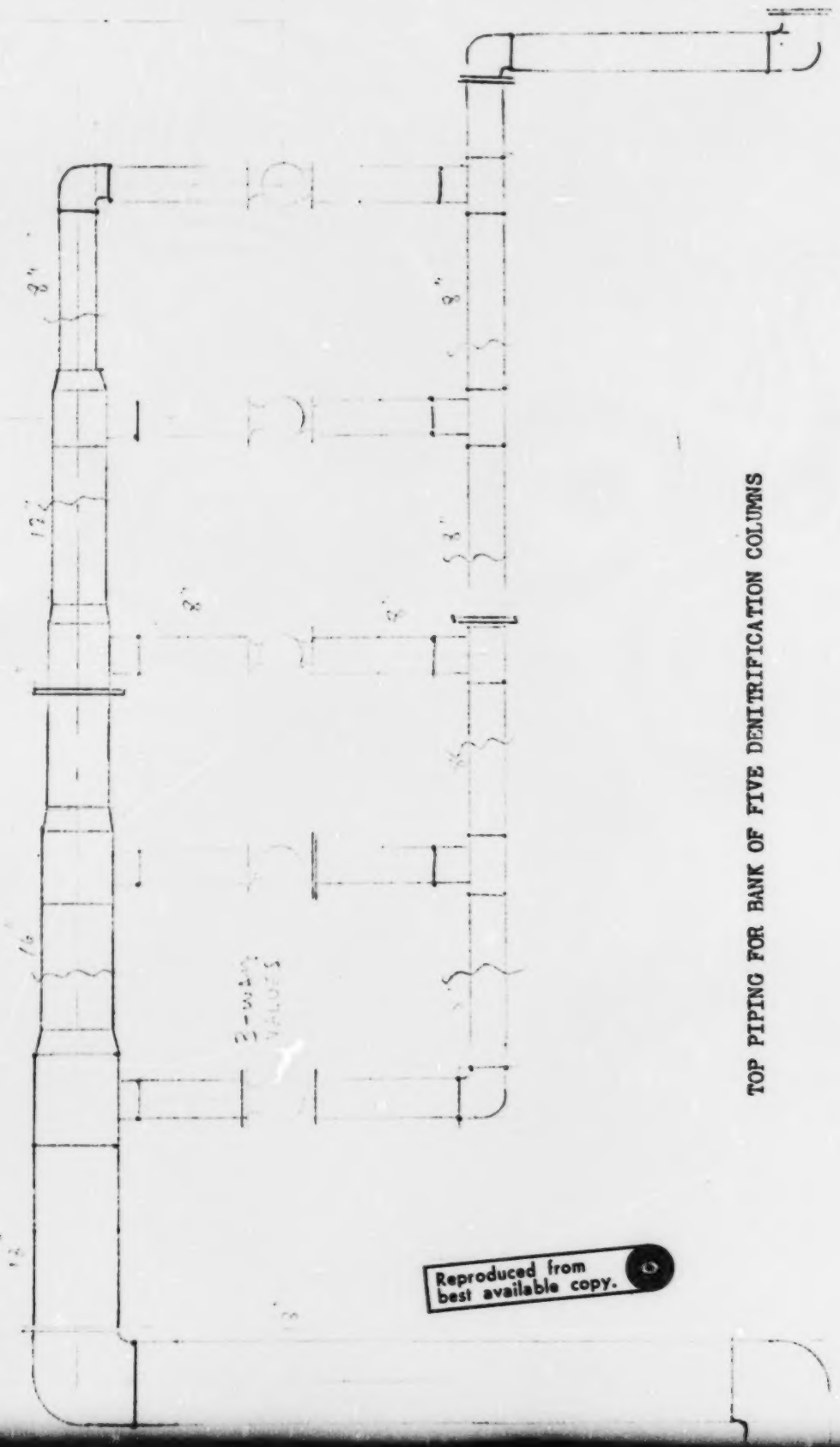
FIGURE 3



Scale: 1/10 in. = 1 ft

PIPING ISOMETRIC FOR
COLUMNAR DENITRIFICATION
(5 columns)

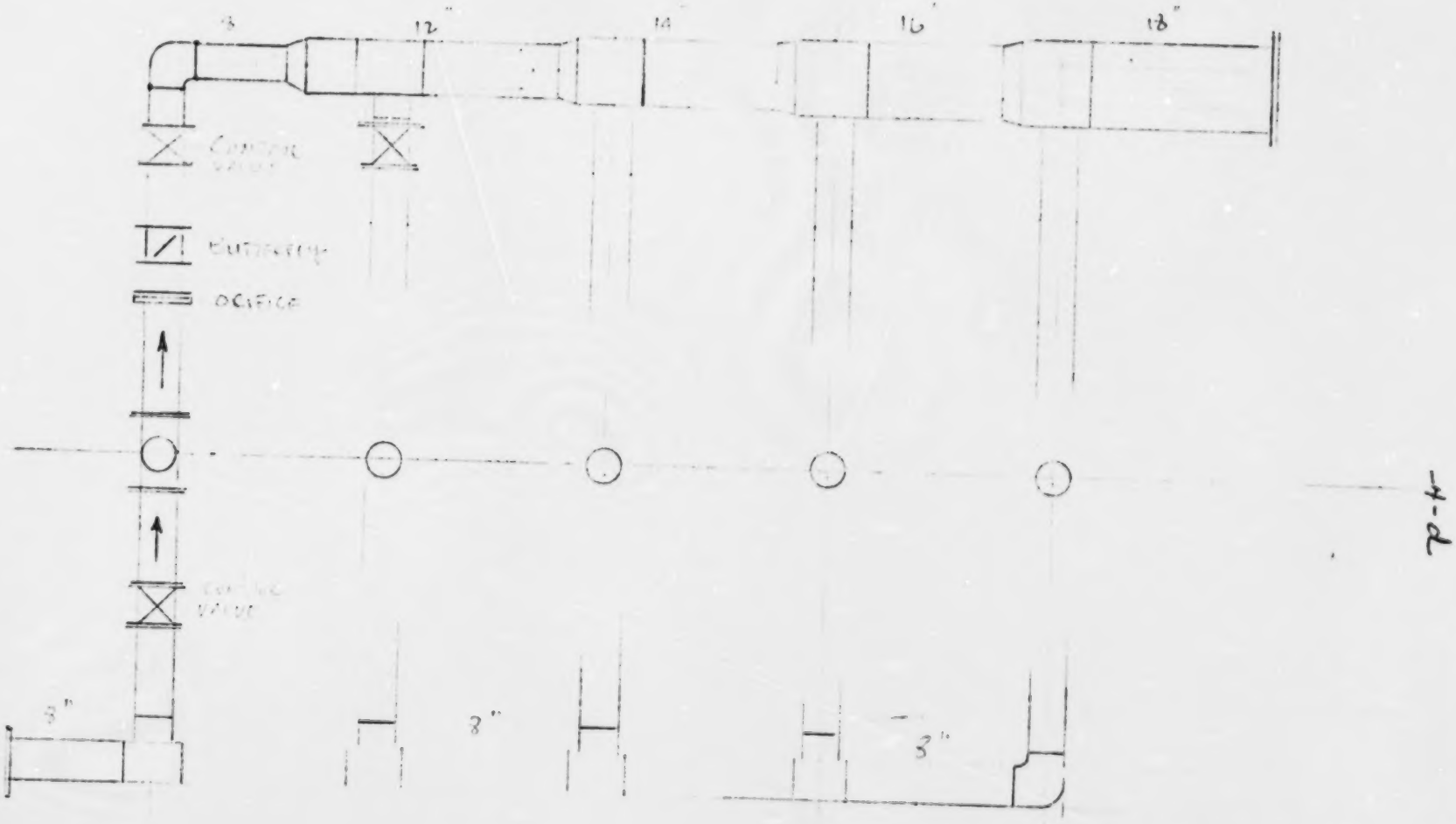
FIGURE 4



TOP PIPING FOR BANK OF FIVE DENITRIFICATION COLUMNS

FIGURE 5

Reproduced from best available copy.



BOTTOM PIPING FOR BANK OF FIVE DENITRIFICATION COLUMNS

FIGURE 6

TABLE III

COLUMNAR DENITRIFICATION

Top Piping

18" Fittings		
2 Elbow @ $241.30 ea.	$ 482.60	
2 Flanges @ $211.34 ea.	422.68	
1 Tee	412.04	
1 18"-16" Reducer	180.25	
30 ft. Pipe	1000.00	
Total		$2497.57
16" Fittings		
1 Tee	$ 287.49	
1 16"-14" Reducer	143.29	
Total		$ 430.78
14" Fittings		
1 Tee	$ 237.82	
1 14"-12" Reducer	107.10	
64 ft. Pipe	1625.00	
Total		$1969.92
12" Fittings		
1 Tee	$ 156.72	
1 12"-8" Reducer	80.92	
Total		$ 237.64
8" Fittings		
4 Elbows @ $66.15	$ 264.60	
15 Flanges @ $17.04	255.60	
10 Buttwelds @ $21.00	210.00	
4 Tees @ $82.35	329.40	
94 ft. 8" Pipe	1600.00	
50 ft. 8" Pipe	800.00	
Total		$3459.60
GRAND TOTAL		$8595.51

TABLE III (Cont'd.)

COLUMNAR DENITRIFICATION

Bottom Piping

18" Pipe		
1 Tee	$ 412.04	
1 Flange	186.10	
1 18"-16" Reducer	180.25	
Total		$ 778.39
16" Pipe		
1 Tee	$ 287.49	
1 16"-14" Reducer	143.29	
Total		$ 430.78
14" Pipe		
1 Tee	$ 237.82	
1 14"-12" Reducer	107.10	
Total		$ 344.92
12" Pipe		
1 Tee	$ 156.72	
1 12"-8" Reducer	80.92	
Total		$ 237.64
8" Pipe and Fittings		
2 Elbows @ $66.15	$ 132.30	
9 Tees @ $82.35	741.15	
41 Flanges @ $41.84	1715.44	
Total		$2,588.89
GRAND TOTAL		$4,380.62

TABLE III (Cont'd.)

COLUMNAR DENITRIFICATION

Meters and Controls

3 Air Headers, 1" Service Pipe	$ 475.80
Column Pressure Drop	
5 Pressure Indicators @ $455.80	2,279.00
5 Pressure Recorders @ $485.69	2,428.45
5 Installation of Pressure Indicators @ $123.00	615.00
5 Air Supply Piping @ $146.00	730.00
5 Air Signal Connections @ $80.00	400.00
Total	$ 6,542.45
Main Connecting Valves	
5 8" Three Way Pneumatic Valves @ $1,905.99	$ 9,529.95
5 Air Signal Connections @ $80.00	400.00
Total	$ 9,929.95
Flow Balance Between Columns	
5 8" Orifice Flange Unions @ $233.17	$ 1,165.85
5 8" Orifice Plates @ $93.41	467.05
5 D/P Transmitters @ $505.30	2,526.50
5 Installation of Transmitters @ $323.00	1,615.00
5 Air Supply Piping @ $146.00	730.00
10 Air Signal Connections @ $80.00	800.00
5 Recorder-Controllers @ $1,148.22	5,741.10
5 8" Control Valves	8,013.60
Total	$21,059.10
Backwash Control	
5 8" Butterfly On-Off Valves @ $529.72	$ 2,648.00
5 2" Orifice Flange Unions @ $92.44	462.20
5 2" Orifice Plates @ $35.98	179.90
5 D/P Transmitters @ $505.30	2,526.50
5 Installation of Transmitters @ $323.00	1,615.00
5 Air Supply Piping @ $146.00	730.00
15 Air Signal Connections @ $80.00	1,200.00
5 Flow Recorder and Totalizers @ $732.00	3,660.00
Total	$13,021.60

TABLE III (Cont'd.)

Surface Wash Control	
5 2" On-Off Ball Valves @ $203.18	$ 1,015.90
5 Air Signal Connections @ $80.00	400.00
Total	$ 1,415.90
Control Panel	
Panel 7' 6" high and 16' long @ $245.00 per ft.	$ 3,920.00
Air Header @ $35/ft.	560.00
Installation of 15 Recorders @ $75.00	1,125.00
Installation of 10 Air Switches @ $44.00	440.00
Total	$ 6,045.00
GRAND TOTAL for Meters and Controls	$58,399.80

The cost of such a pump station was taken from the recent Black and Veatch cost estimates[3] for recirculation pumping stations. The pump station is sized on the peak flow. It was assumed that on-off operation of the pumps, such as that often used in influent pumping stations, would be inadequate for this application. Equipment which matches the pumping rate to the influent flow rate is manufactured by FloMatcher Inc. of Corvallis, Oregon. The cost estimate provides for installation of this equipment. A chart showing the equipment cost for FloMatcher is shown in Figure 7. Thirty percent of the equipment cost was allowed for installation. Two 2500 gpm pumps were provided for backwashing. The cost of pumps were obtained from Ingersall Rand and the cost of the drive motors from Westinghouse.

Surface wash pumps were sized at 160 gpm and 300 ft. head.

METHANOL FEEDING AND STORAGE

At 60 mg/l average feed rate for methanol, about 500 pounds will be used per million gallons. This corresponds to 75 gallons per day or 3.1 gph. The size of the storage tanks must be at least 7500 gallons to allow for delivery by tank truck. The storage capacity should be at least 10 days supply with 30 days supply preferable. For the 1 mgd plant, an underground storage tank of 8000 gallons was provided. At the 10 mgd size, an underground storage tank of 20,000 gallons was provided. This is equivalent to the amount used in 27 days. At the 100 mgd size, an underground storage of 100,000 was provided corresponding to 13.3 days of use. Since these tanks will normally be buried in

ESTIMATED COST OF FLOMATCHER EQUIPMENT

Includes motor starters but does not include pumps and motors

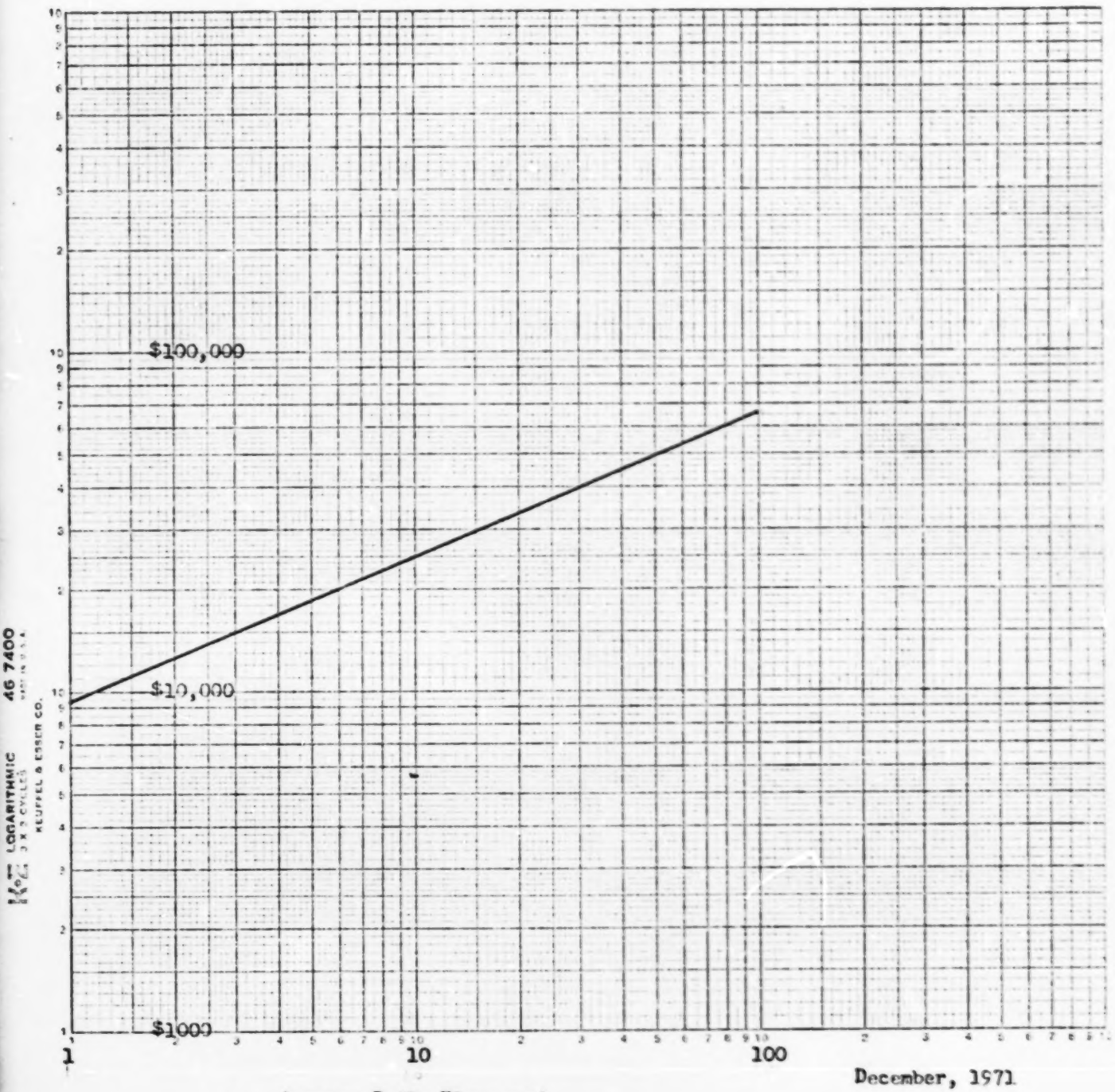


FIGURE 7

the flood plain, it was necessary to anchor the tanks with reinforced concrete to prevent floating. A coating of baked phenolic on the inside and bituminous coating on the outside was provided. A complete cost estimate for underground storage of methanol is shown in Table IV.

The manufacturers of liquid feed pumps recommended that a head tank be provided to assure pump prime at all times. The cost of liquid feed pumps (stainless steel) and the head tank are shown in Table V. Pneumatic control equipment has been provided to proportion the methanol feed rate to the volume flow. The signal which is proportional to flow will be taken from the FloMatcher Equipment.

The estimated capital cost of columnar denitrification, based on the detailed cost estimates presented, are shown in Tables VI, VII, and VIII. A sketch of the 10 mgd plant is shown in Figure 8.

OPERATING AND MAINTENANCE COST

Operating and maintenance cost for the pumping station was taken from the Black and Veatch[3] relationships, with the exception of electrical power for pumping. The cost of pumping the main stream through the columns was computed on the basis of an average pumping pressure of 30 psig. The Black and Veatch estimates for electrical power were based on 30 ft. of water; thus, the Black and Veatch estimates were multiplied by a factor of 2.3.

TABLE IV

ESTIMATED COST OF UNDERGROUND METHANOL STORAGE TANKS

ONE MGD PLANT SIZE - 8000 gallons tank capacity

One 10 ft dia x 14 ft long tank delivered	$ 1,123
Baked Phenolic Coating Inside @ $1.70/sq ft	1,020
Bituminous Coating Outside @ $1.00/sq ft	600
Excavation, 167 cy @ $2.60/cy	434
Reinforced Concrete Saddle, 17 cy @ $200/cy	1,360
Sand and Gravel Backfill, 100 cy @ $5/cy	500
Labor for Backfill, 100 cy @ $2.50/cy	250
Two Mile Haul and Grade at Dump	126
Mobilization and Demobilization of Shovel	700
Sub-total	6,113
Overhead and Profit @ 20%	1,223
TOTAL	$ 7,336

TEN MGD PLANT SIZE - 20,000 gallons tank capacity

One $10\frac{1}{2}$ ft dia x 31 ft long tank delivered	$ 2,555
Baked Phenolic Coating Inside @ $1.60 sq ft	1,920
Bituminous Coating Outside @ $1.00/sq ft	1,200
Excavation, 300 cy @ $2.60/cy	780
Reinforced Concrete Saddle, 45 cy @ $150/cy	2,925
Sand and Gravel Backfill, 200 cy @ $5/cy	1,000
Labor for Backfill, 100 cy @ $2.50/cy	500
Two Mile Haul and Grade at Dump	300
Mobilization and Demobilization of Shovel	700
Sub-total	11,880
Overhead and Profit @ 20%	2,376
TOTAL	$14,256

ONE HUNDRED MGD PLANT SIZE-- 100,000 gallons tank capacity

Five $10\frac{1}{2}$ ft dia x 31 ft long tank delivered	$12,775
Baked Phenolic Coating Inside @ $1.60/sq ft	9,600
Bituminous Coating Outside @ $1.00/sq ft	6,000
Excavation, 1500 cy @ $2 60/cy	3,900
Reinforced Concrete Saddle, 225 cy @ $100/cy	14,625
Sand and Gravel Backfill, 500 cy @ $5/cy	2,500
Labor for Backfill, 500 cy @ $2.50/cy	1,250
Two Mile Haul and Grade at Dump	1,500
Mobilization and Demobilization of Shovel	700
Sub-total	52,850
Overhead and Profit @ 20%	10,570
TOTAL	$63,420

TABLE V

ESTIMATED COST OF METHANOL FEED SYSTEM

ONE MGD PLANT SIZE - 6 gallons per hour	
Two 6 gph liquid feed pumps @ $1792 ea.	$ 3,584
Install two pumps, 8 hr ea. @ $20/hr.	320
One Head Tank and Supply Pump	1,105
Head Tank and Supply Pump Installation	100
Plumbing	474
Pneumatic Pump Controller	520
One Transmitter	505
One Recorder	600
Pneumatic Piping	969
One Air Compressor Installed	500
TOTAL	$ 8,677
TEN MGD PLANT SIZE - 60 gallons per hour	
Two 60 gph liquid feed pumps @ $1967	$ 3,934
Install two pumps, 8 hr. ea. @ $20/hr.	320
One Head Tank and Supply Pump	1,105
Head Tank and Supply Pump Installation	100
Plumbing	474
Pneumatic Pump Controller	520
One D/P Transmitter	505
One Recorder	600
Pneumatic Piping	969
One Air Compressor Installed	500
TOTAL	$ 9,027
ONE HUNDRED MGD PLANT SIZE - 600 gallons per hour	
Four 200 gph liquid feed pumps @ $1967	$ 7,868
Install four pumps, 8 hr. ea. @ $20/hr.	640
One Head Tank and Supply Pump	1,500
Head Tank and Supply Pump Installation	100
Plumbing	900
Pneumatic Pump Controller	520
One D/P Transmitter	505
One Recorder	600
Pneumatic Piping	969
One Air Compressor Installed	500
TOTAL	$14,102

TABLE VI

CAPITAL COST ESTIMATE FOR COLUMNAR DENITRIFICATION
ONE MGD DESIGN CAPACITY
January, 1971

1.	3 Pressure Vessels, 12 ft. dia. x 21 ft. high @ $16,506	$ 49,518	
	Transport of Pressure Vessels, 200 mi at $1.10/100 lb.	957	
	176 cy of ¼ inch rock media, @ $5./cy	880	
	Installation of Pressure Vessels	4,215	
			$ 55,570
2.	Top Piping for Pressure Vessels, @ $8,596/bank of 5	15,473	
	Bottom Piping for Pressure Vessels, @ $4,381/bank of 5	13,143	
			28,616
3.	Meters and Controls, @ $56,464/bank of 5		40,763
4.	Backwash and Surface Wash Pumps		17,259
5.	Influent Pump Station, 2.0 mgd firm capacity (lump sum)	$ 44,000	
	Interconnecting Piping	5,000	
	FloMatcher Equipment Installed	12,090	
			61,090
6.	Concrete Slab, 1 ft. thick x 1520 sq. ft. @ $80/cy		4,500
7.	Underground Methanol Storage Tank, 20,000 gal.		7,336
8.	Methanol Feed System, 60 gph		8,677
	TOTAL CONSTRUCTION COST		$ 223,811
	Land Required = .25 acre @ $2000/acre		500
	Engineering		44,000
	Subtotal		$ 268,311
	Legal, Fiscal and Administrative		7,000
	Subtotal		$ 275,311
	Interest During Construction @ 6%		9,000
	GRAND TOTAL		$ 284,311

TABLE VII

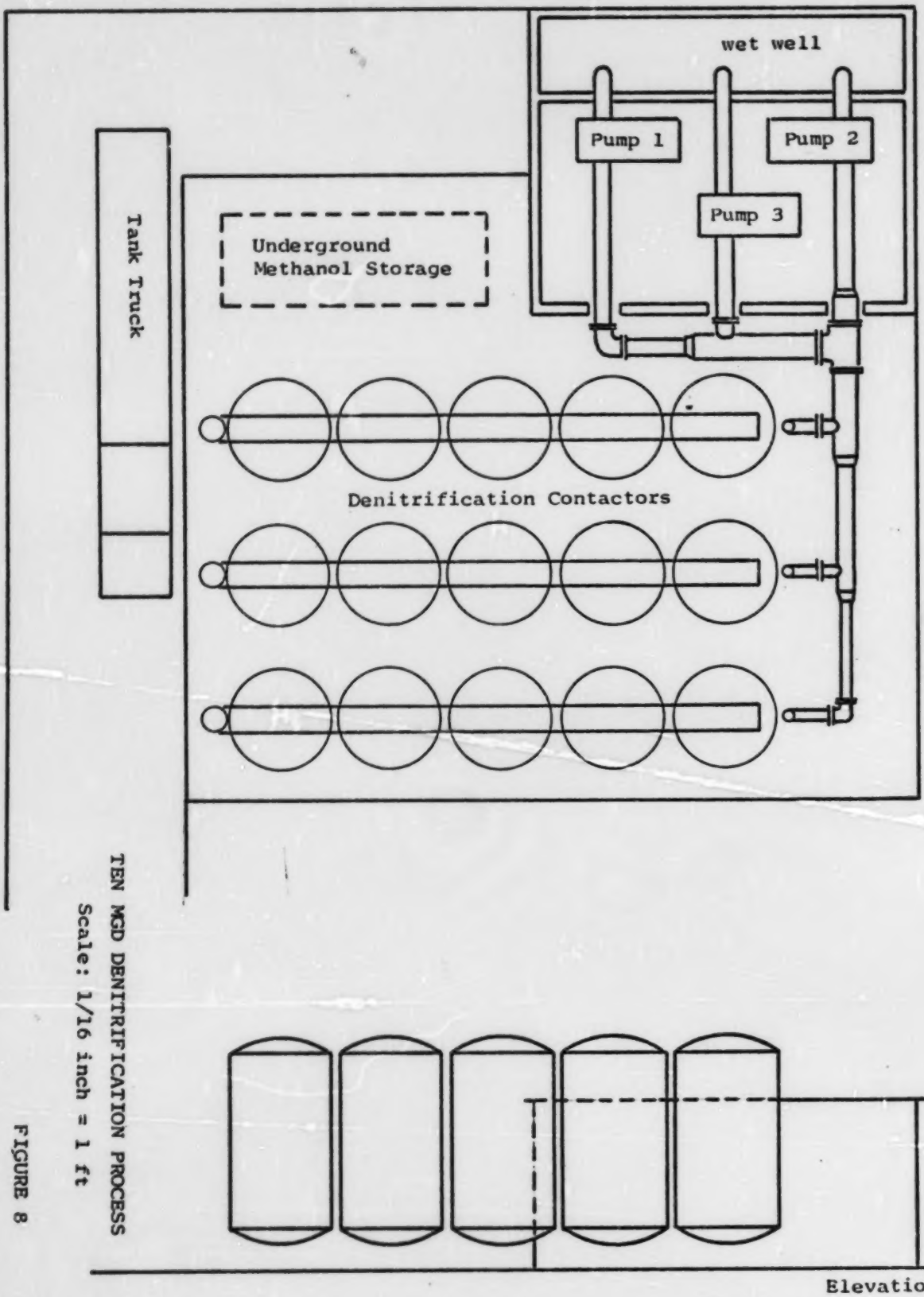
CAPITAL COST ESTIMATE FOR COLUMNAR DENITRIFICATION
TEN MGD DESIGN CAPACITY
January, 1971

1.	15 Pressure Vessels, 12 ft. dia. x 21 ft. high @ $16,506	$247,590	
	Transport of Pressure Vessels, 200 mi at $1.10/100 lb.	4,785	
	880 cy of ¼ inch rock media, @ $5./cy	4,400	
	Installation of Pressure Vessels	21,075	
			$ 277,850
2.	Top Piping for Pressure Vessels, @ $8,596/bank of 5	25,788	
	Bottom Piping for Pressure Vessels, @ $4,381/bank of 5	21,905	
			47,693
3.	Meters and Controls, @ $56,464/bank of 5		175,200
4.	Backwash and Surface Wash Pumps		17,259
5.	Influent Pump Station, 16 mgd firm capacity (lump sum)	$172,000	
	Interconnecting Piping	15,000	
	Flo Matcher Equipment Installed	32,500	
			219,500
6.	Concrete Slab, 1 ft. thick x 5720 sq. ft. @ $80/cy		17,000
7.	Underground Methanol Storage Tank, 20,000 gal.		14,256
8.	Methanol Feed System, 60 gph		9,027
	TOTAL CONSTRUCTION COST		$ 777,785
	Land Required = 0.5 acre @ $2000/acre		1,000
	Engineering		130,000
	Subtotal		$ 908,785
	Legal, Fiscal and Administrative		15,000
	Subtotal		$ 923,785
	Interest During Construction @ 6%		50,000
	GRAND TOTAL		$ 973,785

TABLE VIII

CAPITAL COST ESTIMATE FOR COLUMNAR DENITRIFICATION
ONE HUNDRED MGD DESIGN CAPACITY
January, 1971

1.	115 Pressure Vessels, 12 ft. dia. x 21 ft. high @ $16,506	$1,898,190	
	Transport of Pressure Vessels, 200 mi at $1.10/100 lb.	36,685	
	6750 cy of ¼ inch rock media, @ $5./cy	33,733	
	Installation of Pressure Vessels	161,575	
			$2,130,183
2.	Top Piping for Pressure Vessels, @ $8,596/bank of 5	197,708	
	Bottom Piping for Pressure Vessels, @ $4,381/bank of 5	167,938	
			365,646
3.	Meters and Controls, @ $56,464/bank of 5		1,343,200
4.	Backwash and Surface Wash Pumps		34,518
5.	Influent Pump Station, 130 mgd firm capacity (lump sum)	$ 930,000	
	Interconnecting Piping	30,000	
	FloMatcher Equipment Installed	86,000	
			$1,046,000
6.	Concrete Slab, 1 ft. thick x 40,000 sq. ft. @ $80/cy		119,000
7.	Underground Methanol Storage Tank, 20,000		63,420
8.	Methanol Feed System, 60 gph		14,102
	TOTAL CONSTRUCTION COST		$5,116,069
	Land Required = 3 acre @ $2000/acre		6,000
	Engineering		500,000
	Subtotal		$5,622,069
	Legal, Fiscal and Administrative		41,000
	Subtotal		$5,663,069
	Interest During Construction @ 6%		480,000
	GRAND TOTAL		$6,143,069



TEN MGD DENITRIFICATION PROCESS

Scale: 1/16 inch = 1 ft

FIGURE 8

Operating labor for the denitrification columns were based on the experience at the 7.5 mgd Lake Tahoe Advanced Waste Treatment Plant[4] and at the Youngstown Sheet and Tube Company[5] hot strip mill waste treatment plant. These two points are shown plotted in Figure 9. Operating man-hour requirements were taken from this plot.

Estimates for maintenance on the denitrification columns were very scattered. For example, one principal supplier of pressure filters estimated total maintenance cost at 0.2-0.5% of plant investment. Maintenance cost for pressure filters from the Lake Tahoe Plant, including manpower, materials and supplies, and contracted instrument maintenance, were reported as about 1.67% of the capital cost of the filters. These estimates are low compared to the nominal values of 3-5% of plant investment used in the process industries. In this cost estimate, the total cost of maintenance was taken as 1% of the capital cost.

Electrical power for backwashing and surface spray was computed assuming that each column would be backwashed for 15 minutes per day and the wire-to-water efficiency was estimated at 50%. The cost of electrical power was taken as 1.2 cent/KwHr.

The concentration of nitrate nitrogen was assumed to be 20 mg/l. The ratio of methanol to nitrate nitrogen was taken as 3.0, thus the

MAN-HOUR REQUIREMENTS FOR OPERATION OF DENITRIFICATION COLUMNS versus DESIGN CAPACITY, MGD

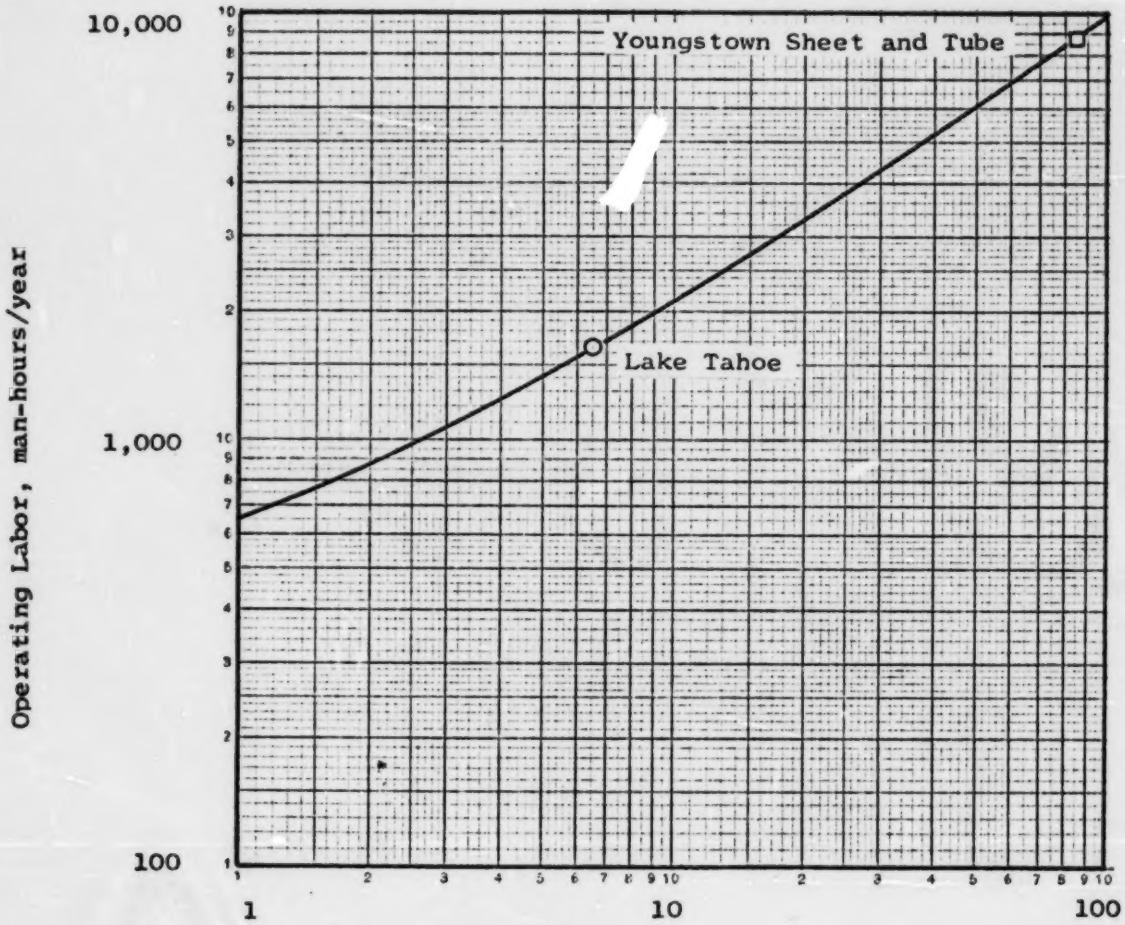


FIGURE 9

average dose of methanol was 60 mg/l. The cost of methanol delivered was 27 cents/gallon. Methanol weighs 6.60 pounds per gallon. If we set the backwash rate at 20 gpm/sq. ft., the amount of backwash water which must be returned to the conventional plant will be 33929 gallons per contactor. For the 10 mgd plant this would be 14 x 34 or 476 thousand gallons/day or 4.76% of the throughput. The question then arises whether a cost for backwash water should be charged to the denitrification process.

The COD of methanol is about 1.5 times the methanol concentration. Thus, the COD of 60 mg/l methanol is about 90 mg/l COD. The generally accepted synthesis factor for heterotrophs is 1.42 mg/l of COD per mg/l of VSS. Thus, the volatile solids produced in the column as a result of the denitrification process should be about 90/1.42 or 63.4 mg/l VSS. If we add about 20 mg/l to represent the loss of solids over the weirs of the nitrification process, the total would be 83.4 mg/l. Taking the backwash water as approximately 5% of the throughput, the concentration of volatile solids in the backwash water should be about 20 x 83.4 or 1668 mg/l VSS. It would appear that as a minimum, we should charge the denitrification process for disposal of the sludge. If the backwash is made to coincide with the low flow periods, the hydraulic effect on the plant may be a minimum, except for the small sized plants. The total cost of treating water in an activated sludge plant (10 mgd) with sludge handling capability is about 12 cents/1000 gal. Roughly, one-third of this is attributable to sludge handling and disposal. A

normal 10 mgd secondary plant produces about 20,000 lb. of dry solids per day or 10 tons per day. Thus, the cost of sludge handling and disposal, costs roughly $40 per ton at the 10 mgd size. As a minimum, the charge for the backwash water should be 4 cents/1000 gal. If we assume that 5% of the water is used for backwash, the charge, in terms of the throughput, would be 0.2 cents/1000 gal.

A summary of estimates for operation and maintenance are shown in Table IX. The cost of backwash water has not been included; first, because it is a small fraction of the total cost and second, because the basis for assigning the cost is questionable.

SUMMARY

A detailed cost estimate for columnar denitrification has been made. The estimated costs are shown graphically in Figure 10. In order to compare the cost of columnar denitrification with denitrification in dispersed floc reactors, a detailed cost estimate for denitrification in dispersed floc reactors is presented in Tables X, XI, XII, and XIII and Figure 11. The cost estimates presented here for columnar denitrification are somewhat greater than those given for dispersed floc reactors. The ratio of capital cost is about 1.3 for all sizes between 1 mgd and 100 mgd. The operating and maintenance cost estimates are roughly the same.

Although it appears, as a result of this study, that columnar denitrification is somewhat more expensive than dispersed floc

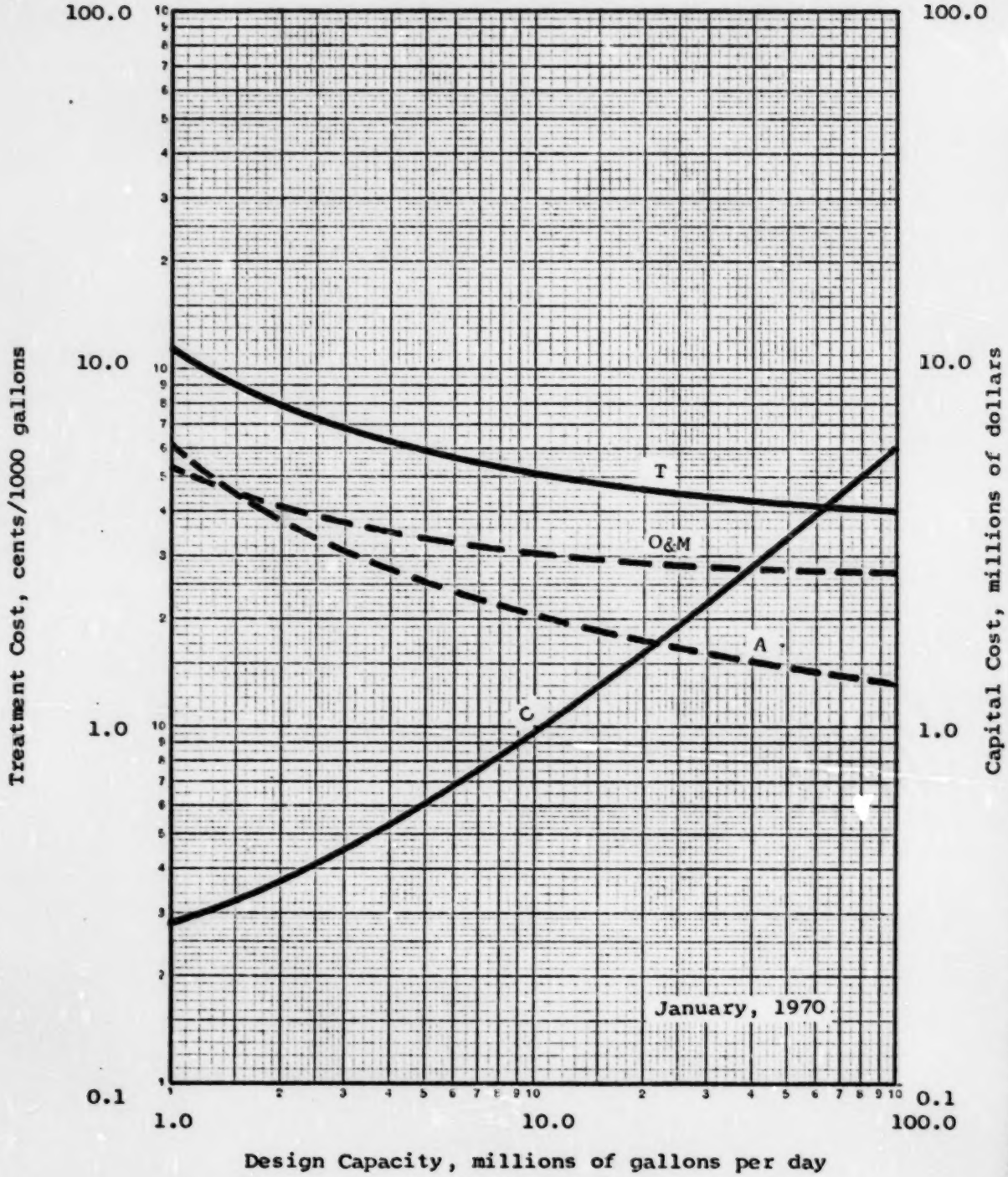
TABLE IX

OPERATING AND MAINTENANCE COST FOR COLUMNAR DENITRIFICATION

	1 mgd		10 mgd		100 mgd	
I. PUMPING STATION	mh	$	mh	$	mh	$
Operating Labor, mh/yr @ $3.85/hr	480	1,848	720	2,772	3,000	11,550
Maintenance Labor, mh/yr @ $3.85/hr	390	1,502	600	2,310	2,200	8,470
Fringe Benefits @ 15%		503		762		3,003
Materials and Supplies		350		1,700		16,000
Electrical Power		2,123		12,000		103,846
Subtotal dollars/yr		6,326		19,544		142,869
cents/1000 gallons		1.73		.535		.391
II. PRESSURE VESSELS AND ASSOCIATED EQUIPMENT						
Operating Labor, mh/yr @ $3.85/hr	650	2,503	1,950	7,508	9,700	37,345
Fringe Benefits @ 15% of Operating Labor		375		1,126		5,602
Total Maintenance Cost @ 1% of PI		2,403		8,018		52,131
Electrical Power @ 1.2 cents/KwHr		234		1,752		13,432
Subtotal, dollars/yr		5,515		18,404		108,510
cents/1000 gallons		1.51		.504		.30
III. METHANOL @ 27¢/gal						
dollars/yr		7,463		74,628		746,279
cents/1000 gal		2.04		2.04		2.04
GRAND TOTAL						
dollars/yr		19,304		112,576		997,658
cents/1000 gal		5.29		3.08		2.73

DENITRIFICATION IN COLUMNS

Capital Cost, Operating and Maintenance Cost, Debt Service
vs
Design Capacity



C = Capital Cost, millions of dollars
A = Debt Service, cents per 1000 gallons (6% - 25 yr.)
O + M = Operating and Maintenance Cost, cents per 1000 gallons
T = Total Treatment Cost, cents per 1000 gallons

FIGURE 11

TABLE X

CAPITAL COST ESTIMATES FOR DENITRIFICATION IN DISPERSED FLOC BASINS DOWNSTREAM OF THE ACTIVATED SLUDGE PROCESS
January, 1971

	PROCESS COMPONENTS	1 mgd	10 mgd	100 mgd
1.	Denitrification Tanks	$ 30,755	$142,800	$1,319,000
2.	Agitators	13,700	26,150	261,400
3.	Recycle Pumps	34,000	110,000	439,000
4.	Final Settlers	49,400	275,000	1,538,000
5.	Methanol Feed System	8,677	9,027	14,102
6.	Methanol Storage Facilities	7,336	14,256	63,420
	Subtotal	$143,868	$577,233	$3,634,922
	Yardwork @ 14% of Subtotal	20,142	80,813	508,889
	TOTAL CONSTRUCTION COST	$164,010	$658,046	$4,143,811
	Land Required, acres	.2	.5	3
	Land Cost @ $2000 per acre	400	1,000	6,000
	Engineering	29,000	80,000	350,000
	Subtotal	$193,410	$739,046	$4,499,811
	Legal, Fiscal and Administrative	5,200	12,500	33,000
	Subtotal	$198,610	$751,546	$4,532,811
	Interest During Construction	4,600	30,000	280,000
	GRAND TOTAL	$203,210	$781,546	$4,812,811
	LEVEL DEBT SERVICE			
	@ 6% and 25 yr. cents/1000 gallons	4.36	1.68	1.03

TABLE XI

COST ESTIMATES FOR DENITRIFICATION IN DISPERSED FLOC REACTORS

DESIGN AVERAGE FLOW = 1.0 mgd NATIONAL AVERAGE COST, January, 1971

PROCESS COMPONENTS	Operation mh/yr	Maintenance mh/yr	Total Direct Labor mh/yr	Materials, Supplies, and Utilities $/yr
1. Denitrification Tanks (2 hr)	700	340	1,040	2,050
2. Denitrification Recycle Pumps	440	330	770	3,076
3. Denitrification Sedimentation	195	150	345	223
Total Man-hours per Year			2,155	
Total Annual Dollar for Materials, Supplies, and Utilities				5,349
Total Annual Salaries with 15% Fringe Benefits ($3.85/man-hour)				9,541
Total Annual Dollars for Salaries and Materials, Supplies, and Utilities				14,890
Yardwork, Laboratory, and Administrative and General @ 13.2% of Total				3,931
TOTAL ANNUAL COST FOR OPERATION AND MAINTENANCE				18,821
OPERATION AND MAINTENANCE COST, CENTS/1000 GALLONS				5.16
COST OF METHANOL (60 mg/l @ $0.27/gallon), CENTS/1000 GALLONS				2.04
TOTAL OPERATION AND MAINTENANCE COST, CENTS/1000 GALLONS				7.20

TABLE XII

COST ESTIMATES FOR DENITRIFICATION IN DISPERSED FLOC REACTORS

DESIGN AVERAGE FLOW = 10 mgd NATIONAL AVERAGE COST, January, 1971

PROCESS COMPONENTS	Operation mh/yr	Maintenance mh/yr	Total Direct Labor mh/yr	Materials, Supplies, and Utilities $/yr
1. Denitrification Tanks (2 hr)	1,270	800	2,070	4,094
2. Denitrification Recycle Pumps	870	620	1,490	5,515
3. Denitrification Sedimentation	1,050	680	1,730	1,082
Total Man-hours per Year			5,290	
Total Annual Dollars for Materials, Supplies, and Utilities				10,691
Total Annual Salaries with 15% Fringe Benefits ($3.85/man-hour)				23,422
Total Annual Dollars for Salaries and Materials, Supplies, and Utilities				34,113
Yardwork, Laboratory, and Administrative and General @ 13.2% of Total				4,503
TOTAL ANNUAL COST FOR OPERATION AND MAINTENANCE				38,616
OPERATION AND MAINTENANCE COST, CENTS/1000 GALLONS				1.06
COST OF METHANOL (60 mg/l @ $0.27/gallon), CENTS/1000 GALLONS				2.04
TOTAL OPERATION AND MAINTENANCE COST, CENTS/1000 GALLONS				3.10

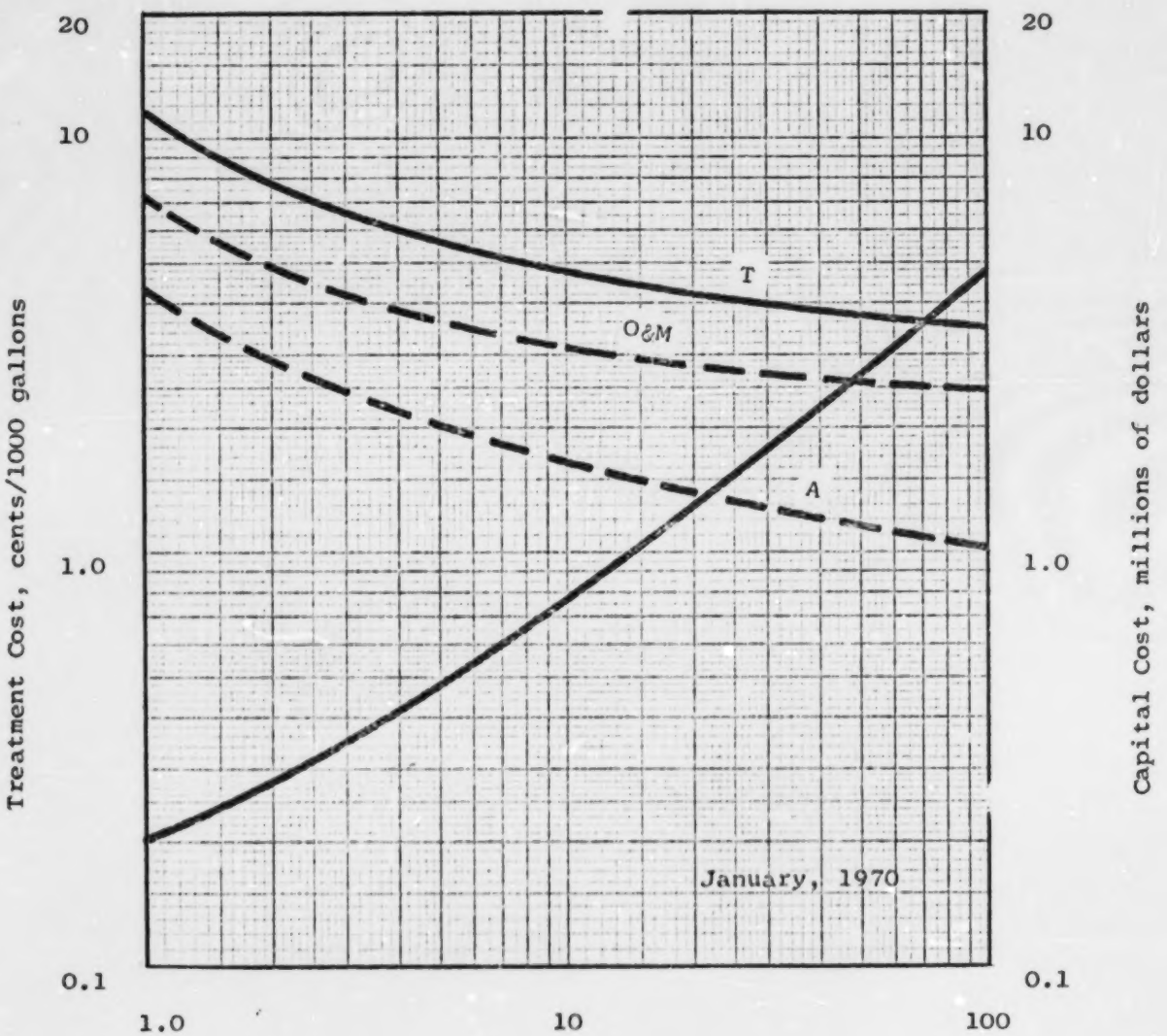
TABLE XIII

COST ESTIMATES FOR DENITRIFICATION IN DISPERSED FLOC REACTORS
DESIGN AVERAGE FLOW = 100 mgd NATIONAL AVERAGE COST, January, 1971

PROCESS COMPONENTS	Operation mh/yr	Maintenance mh/yr	Total Direct Labor mh/yr	Materials, Supplies, and Utilities $/yr
1. Denitrification Tanks (2 hr)	6,133	4,800	10,933	8,113
2. Denitrification Recycle Pumps	1,700	1,200	2,900	9,863
3. Denitrification Sedimentation	6,600	3,400	10,000	5,303
Total Man-hours per Year			23,833	
Total Annual Dollars for Materials, Supplies, and Utilities				23,279
Total Annual Salaries with 15% Fringe Benefits ($3.85/man-hour)				105,521
Total Annual Dollars for Salaries and Materials, Supplies, and Utilities				128,800
Yardwork, Laboratory, and Administrative and General @ 13.2% of Total				17,000
TOTAL ANNUAL COST FOR OPERATION AND MAINTENANCE				145,800
OPERATION AND MAINTENANCE COST, CENTS/1000 GALLONS				0.40
COST OF METHANOL (60 mg/l @ $0.27/gallon), CENTS/1000 GALLONS				2.04
TOTAL OPERATION AND MAINTENANCE COST, CENTS/1000 GALLONS				2.44

DENITRIFICATION IN DISPERSED FLOC REACTORS

Capital Cost, Operating and Maintenance Cost, Debt Service
vs
Design Capacity



C = Capital Cost, millions of dollars
A = Debt Service, cents per 1000 gallons (6% and 25 yr.)
O&M = Operating and Maintenance Cost, cents per 1000 gallons
T= Total Treatment Cost, cents per 1000 gallons

FIGURE 10

denitrification, it should be emphasized that further cost studies could result in a reduced cost estimate for columnar denitrification. For example, it was assumed that all pressure vessels would be shop fabricated and that pressure vessels would be used in all cases rather than open bed contactors. The maximum size pressure vessel which can be easily transported from shop to plant site is 12 ft. in diameter. A study to determine the cost of field fabricated pressure vessels is now underway and the use of larger field fabricated vessels may reduce the cost of the process. The use of large concrete contactors open to the atmosphere, is another possibility which could reduce the process cost. The application rate for contactors open to the atmosphere would be much less than the 7 gpm/sq. ft. assumed; the rate for open contactors would probably be in the range 1-2 gpm/sq. ft.

The dispersed floc reactor for the 100 mgd size has a volume of 1,337,000 cu. ft. and a surface area of about 89,000 sq. ft. Using an application rate of 1 gpm/sq. ft., the required area for the columnar denitrification contactor would be about 90,000 sq. ft. The depth of the contactor would be 14 ft. plus a depth of water sufficient to force the water through the rock media. This would be a minimum of 10 ft. Thus, if the allowable rate is 1 gpm/sq. ft., the dispersed floc reactor would probably be less expensive. If the allowable rate is 2 gpm/sq. ft., the area would be only one-half of the area of the dispersed floc tanks, but the depth would be greater than the depth of the dispersed floc tanks. On a unit volume basis, a 24 ft.

deep tank would probably cost more than a 15 ft. deep tank. Thus, based on this superficial analysis, the dispersed floc process for denitrification may be less expensive than columnar denitrification in open concrete contactors.

In making cost estimates for advanced processes, the lack of reliable process design criteria is a major obstacle. For example, the relationship between bed diameter and bed depth is not known with any precision. In pressure contactors it is generally believed that the height should equal or exceed the diameter to minimize channeling and distribution effects. In large contactors open to the atmosphere, this rule is never followed. The height diameter ratio is clearly a function of the application rate, but we have no guidelines on the nature of the function. The relationship between the working pressure of the contactors and the frequency of backwash is unknown. The need to equalize the pressure drop across the contactors is not well established. Whether equalization is preferable to equipment, such as FloMatcher, to hold the rate of pumping equal to the influent volume flow has not been investigated. Some studies have shown that the effect of ambient water temperature can be compensated for by varying the methanol dose. More work is needed on this point. The design of any process is very dependent on the specific requirement for effluent quality. For example, is the target effluent concentration of nitrogen to be achieved at peak flow, on a 24 hr. composite basis, at all ambient temperatures, for all seasons of the year, etc.?

In many cases, our knowledge of process design relationships for the advanced processes are not precise enough to calculate truly optimal designs or to determine the most cost-effective treatment scheme.

REFERENCES

1. Richardson Engineering Services, Inc., Downey, California, "Manual of Commercial and Industrial Construction Estimating Standards," Volumes I, II, III, and IV

2. "Chemical Engineers' Handbook," John H. Perry, Editor, Fourth Edition, McGraw-Hill

3. Patterson, W. L. and Banker, R. F. "Estimating Costs and Manpower Requirements for Conventional Wastewater Treatment Facilities," EPA Water Pollution Control Research Series 17090 DAN 10/71

4. Evans, D. R. and Wilson, J. C. "Capital and Operating Costs - AWT," Journal WPCF, Volume 44, January, 1972, pp 1-13

5. Broman, C. "The Operation of Pressure Type Sand Filters for Hot Mill Waste Waters," Iron and Steel Institute, 1970